IKONOS Interpretive Rulemaking

Interpretive Rules Used in Preparation of Coral Reef Habitat Maps for the Hawaiian Islands

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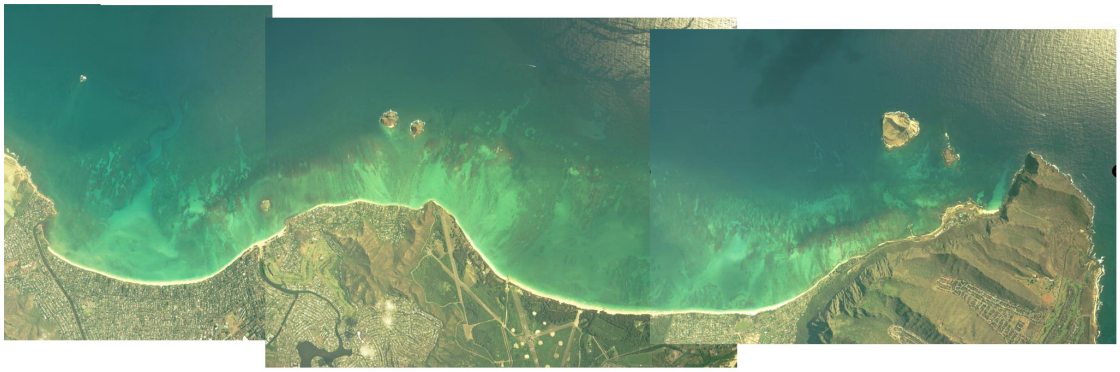

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I. Introduction and Background

The National Oceanic and Atmospheric Administration's (NOAA's) National Ocean Service (NOS) is tasked with the coral mapping element of the U.S. Coral Reef Task Force (CRTF) under the authority of the Clinton Administration Executive Order P.L. 13089. Under this purview, the NOS has been responsible for coral reef mapping in Puerto Rico, U.S. Virgin Islands, the Northwestern Hawaiian Islands and the Main Hawaiian Islands. While coral reef maps provide valuable habitat information that is important for coastal related industries, such as fisheries and tourism, these map products are essential decision-making tools for resource managers tasked with protecting and improving the sustainable management of coral reefs.

In the overall effort to generate coral reef map products suitable for the implementation of these goals, NOAA has acquired digital imagery from several sources that include color aerial photography, hyperspectral and multispectral imagery from both fixed wing airborne as well as satellite platforms. These data have been used to generated coral reef habitat maps that are now being used in long term monitoring programs in the State of Hawaii. These programs are managed by the Government of the State of Hawaii Department of Land and Natural Resources (DLNR), the Hawaii Institute of Marine Biology (HIMB) at the University of Hawaii and the U.S. Environmental Protection Agency (USEPA). The goal for this mapping program includes expanding the area to include the US possessions of the Pacific. As much of this area is remote and access to airborne platforms is very limited and prohibitively expensive, NOAA has explored using satellite imagery from which to prepare these map products.

Traditionally, mapped products that meet these requirements have been derived by manual delineation of reef habitat using photointerpretation of reef features in an image. More recently, automated processing of the spectral composition of imagery is demonstrating that algorithmic processing can generate habitat maps at the major levels of the classification scheme. It is recognized that both approaches have strengths and weaknesses. Human logic is integral to the photointerpretation method and yields acceptable levels of accuracy at a more detailed level of the classification scheme. This method is less vulnerable to error due to variability in environmental conditions at the time the imagery was collected. The automated methods are completely reproducible, faster and have the potential for being reprocessed quickly and easily at a later date.

Thus, several hybrid methods are being developed that combine these two approaches to take advantage of the benefits of both. One approach is to incorporate more of the human logic process into the decision process that software compiles. Of these, spatial information that allows for automated recognition of geophysical or reef morphological features enables the automated processes to generate products with more detailed levels of reef classes.

The purpose of this report is to provide the rules that are used by a photointerpreter that is preparing coral reef habitat maps to NOAA standards. The product will assist in developing the algorithms used for automated mapping of these reef systems using rule based reef habitat recognition software. The rules in this report were generated during the interpretation of IKONOS imagery for four test areas in the Main Hawaiian Islands.

II. Concepts in Interpretation of IKONOS Image Features

It is important to recognize that all habitats that are delineated by photointerpretation are based on what can be seen in the imagery. The delineation of boundaries of a particular reef habitat is based on its color, texture and shape as well as personal knowledge of habitat types and familiarity with the types of biological communities that can potentially constitute a particular habitat type. It is infrequent that two areas that are correctly classified as having the same habitat types look similar in the imagery irrespective of the location in the reef system. A particular habitat in one zone, at one depth or exposed to a particular set of water quality and water motion conditions may look very different than the same habitat type in another set of conditions. Impact from land based activities such as run off, nutrient load and fishing pressure can affect how a particular habitat is "seen" in the imagery. For instance, uncolonized pavement in an area that is adjacent to land runoff and located in a protected intertidal area of a reef flat may be heavily impacted by terriginous sediment causing it to look dark brown. The same habitat on an un-impacted reef crest or fore reef that is sand scoured and where grazing is active, can be so light it is difficult to distinguish from white sand. Furthermore, the same habitat at the same depth and exposed to very similar conditions may look very different. Spur and groove can form very narrow grooves where the bottom of the groove is dark due to shadow. In this case, it looks like alternating narrow dark lines. It can also form wider grooves with white sand in the bottom so the image looks like alternating white lines. Thus similar habitats may look very different and different habitats may look very similar in the imagery.

Habitat Diversity

It is also important to recognize that any minimum mapping unit may be composed of one to several habitat types. A large area of sand will have many minimum mapping units that are pure. However, an area on the reef flat that is just inshore of the reef crest will most likely be a mosaic composed of colonized and uncolonized pavement, aggregated coral, reef rubble, sand, scattered coral and rock and encrusting coralline and macro algae of all ranges of density. Areas of high diversity will inherently be a source of map error if accuracy is assessed using traditional accuracy assessment of resource maps prepared from remotely sensed imagery.

Live Coral Cover

As the presence of live coral, at even low cover, is important to most tropical marine resource managers, many classification schemes favor identification of the presence of live coral over other benthic cover such as algae. One of the most important components of the delineation process is recognizing that the presence of live coral can rarely be "seen" in the imagery. There are two solutions to this paucity of information.

1. Extensive knowledge of the reef area on the part of the photointerpreter. This may exist as local knowledge of the area or be acquired by ground validation in the field or,
2. Identification of areas where live coral cover exists by automated classification of digital imagery.

If imagery is being processed using automated methods that can detect the presence of live coral, then the greatest unknown in the assignment of polygon habitat attributes has been resolved. If the automated processing cannot resolve the presence of live coral then the area to be mapped must be divided into subsets where the distribution of the live coral can be predicted and this must be based on field knowledge. Each area where the probability of there being live coral meets some set standard should be treated as a single subset. For example, the probability of finding substantial amounts of live coral in the lagoon of a closed atoll will be very low and the probability of finding substantial cover of live coral on a moderately exposed fore reef is very high.

Relief

Another important variable is vertical relief. Though the classification scheme used here does not accommodate relief, it is responsible for much of the visible texture and color in any scene. An area of uncolonized pavement can appear as light as white sand to as dark as continuous algae depending on relief. As the relief that causes this appearance in the image can be very small scale (1 to 10 cm in both horizontal and vertical axis), the only way for a photointerpreter to resolve that there is no difference between these habitats is knowledge of the area.

Image Resolution and Color

Within any classification scheme it should also be recognized that the closer an image represents the true color of the features in a scene and the higher the image resolution (smaller pixel/grain size), the better the image can be processed to extract photointerpreted information. If resolution and color were sufficiently high, no field data would be needed because the interpretation of the imagery could not be improved upon by viewing the scene in the field. Conversely, if resolution and color so poorly provide the information needed to classify visible features in the image, the burden of classification is transferred to field surveys or the photointerpreter's knowledge of the scene.

Though the two are inseparable, it is generally assumed that the colors of habitat features are relatively reproducible and are adequate to delineate habitat boundaries. If this criterion is not met, color rather than pixel size is the limiting factor and photo interpretation cannot be conducted, as the features cannot be "seen".

If the photointerpreter has adequate knowledge about the image and the image adequately displays the habitats, the limiting factor becomes pixel size as pixel size ultimately limits the ability to identify habitat boundaries.

Statistical Analysis of Accuracy

During this contract careful examination has been made to establish the accuracy of the map product. Comparisons of aerial color photography (1 meter pixel), AURORA Hyperspectral (3 meter pixel) and IKONOS satellite imagery (4 meter pixel) have been conducted. As the color balance in each of these image types is suitable for photointerpretation, the burden of utility of these images for photointerpretation is biased toward resolution. It is reasonable to conclude that as pixel size increases, a threshold will be encountered where accuracy is sacrificed at an unacceptable level. The results of this work shows that at the major habitat classes, small statistical differences exists between the accuracy of the maps generated when conducted by the a single photointerpreter. Though not statistically analyzed, it also became apparent to the photointerpreter that the larger the pixel size, the more dependent the interpreter was on knowledge of the area. In this study, accuracy of detailed map classes was not examined. However, it was very apparent that at the resolution of the IKONOS satellite imagery, significant familiarity of the mapped area was needed. At a minimum, when preparing coral reef habitat maps from photointerpretation of IKONOS satellite imagery, each area should either be visited by the interpreter or the interpreter should have access to local knowledge regarding the general patterns of habitats in the reef system being mapped.

III. Order of Steps Taken in Preparation of Digitized Coral Reef Habitat Maps

The maps in this project have been developed by "heads up" manual delineation of habitat boundaries by photointerpretation of remote sensing imagery. Digitizing was conducted using the Coral Reef Habitat digitizing extension downloadable on the NOAA web site (http://biogeo.nos.noaa.gov/products/apps/digitizer/). The associated table reflects the classification scheme also available on the NOAA web site (http://biogeo.nos.noaa.gov/projects/mapping/pacific/main8/classification/). During this tenure, a discrete set of steps was developed to secure a reliable and reproducible method. Eight steps are taken when preparing a photointerpreted coral reef habitat map from remotely sensed imagery.

1. The perimeter of the imagery is digitized.
2. The shoreward edge of land is digitized and land is attributed.
3. The seaward edge of the intertidal is digitized including unknown areas typically attributed to surf. At this point the intertidal can be assigned its zone.
4. The habitats in the intertidal are delineated and attributed.
5. Unknown area, which due to depth or other obstruction of the imagery is delineated and attributed as unknown.
6. All sand is delineated
7. Zones are delineated
8. Hardbottom is delineated including submerged aquatic vegetation and colonized and uncolonized hard bottom.

During delineation of habitat boundaries, field surveys are often conducted for ground validation. This process lends further support to the accuracy of the maps and also allows for exploration of areas in the imagery where the determination of habitat type was not certain. These data are reviewed and modifications to the polygon boundaries are made as needed.

When the map is complete, quality checks are conducted. These procedures check the maps for but are not limited to:

1. Multipart polygons,
2. Overlapping polygons,
3. Sliver polygons or polygons of less than the minimum mapping unit,
4. Adjacent polygons (Polygons with the same habitat and zone attributes that are adjacent to one another,
5. Void polygons and
6. Topologically cleans the polygons

Subsequent to production of the final map, the tables are formatted to be compatible with NOAA web posting standards and a CSDGM compliant metadata summary is prepared.

To minimize redundancy in this report, the habitats that have not been delineated in each zone have not been included and the unknown designation is reserved for areas where the habitat cannot be identified for any reason.

IV. Class by Class Rules used in Delineation

Much of the decision making process, when delineating habitat boundaries, is predicated on the ecological zone that the area is in and what is known about the area in general. Zone data is determined by the location of the habitat in the reef system. Though some habitats are restricted to one or two zones, the same habitat may occur in all zones. Here, the rules for the habitats are presented per zone. Seagrass was not delineated in any habitat maps for the Main Eight Hawaiian Islands and was therefore not included in this summary.

1. Shoreline intertidal Zone

Unconsolidated Sediment

Sand:

Sandy areas in the intertidal are usually bright white as the sand is usually bleached by the sun and has little or no water over it to cause color variation. The exception is near young lava flows where the sand is black or gray. These colors are visible in the IKONOS imagery. Look for boulders in the upper intertidal with a smooth black or gray color in the surf zone to suggest where to look for black sand.

Mud:

Mud in the intertidal is usually chocolate brown and has a very smooth texture. Look for indications that there is terriginous runoff at stream mouths or dredging has occurred. Also look for areas that are very sheltered such as areas adjacent to mangroves.

Macroalgae

Usually a very dark green to dark brown colored strip in the surf zone (Often partially obscured by white water) but usually does not extend into more than 2 meters of water depth. It is frequently in the intertidal adjacent to a sandy beach. This area is usually on carbonate beach rock – density is usually between 50-<90% cover. Once the habitat has been located, the lighter colored areas can be assigned 10-<50% cover. If the near shore area that is off shore of the intertidal is very dark brown (Most likely continuous algae) and the beach rock is very dark brown, then attribute this area with "Continuous macro algae".

Uncolonized Hard Bottom

Uncolonized volcanic rock/boulder:

This is the only intertidal habitat that is not emergent vegetation, sand, mud, uncolonized pavement or algae. The roughness of the rock can clearly be seen as contrast between pixels across very short distances. The area that is awash during the image acquisition is usually very dark and almost black.

Encrusting Coralline Algae

This habitat is very common on exposed coastlines in the intertidal area. However, it is rarely detectable in IKONOS, or any type of imagery, as these intertidal areas are commonly very narrow and frequently obscured by white water even on the calmest days.

Other Delineations

Emergent Vegetation

Mangroves and Hao trees are the only emergent vegetation in Hawaii. These two trees are easily identified as they line the landward side of the mud flats in sheltered areas and is continuous forest green showing sharp contrast with the muddy environment offshore. The landward edge of this habitat is nearly impossible to delineate as these trees merge with other green forest vegetation. However the emergent vegetation at the edge of the reef flat is typically uniform dark forest green and easily delineated.

Artificial

Though some artificial features can be recognized in IKONOS imagery, others are rarely resolvable. Hardened substrate it is typically a wall in the shoreline intertidal that is too narrow to be identified in 4-meter resolution imagery such as IKONOS. A long uniform narrow feature typifies cases where it can be identified. Look for linear features in the shoreline intertidal typically with sand on the seaward side. The feature itself may or may not be visible as in the imagery but a very straight line running along the shore is usually a retaining or erosion control devise.

Other man made features such as piers, wharfs, or jetties are easily identified.. Look for features with uniform light color where sections are very linear and distinct angles occur at the edges.

2. Reef Flat and Back Reef Zones

This broad area (usually at least 100 meters wide) is located seaward of the intertidal area (Reef Flat) or landward of a barrier reef where a lagoon exists inshore (Back Reef) and it is occasionally three meters but typically less than two meters deep.

Unconsolidated Sediment

Sand:

Sand appears bright white to light blue to darker blues depending on depth with shallower areas being lighter. From pixel to adjacent pixel, sand is frequently very uniform. There is little change in color or texture over areas where depth is consistent and as depth varies little across the reef flat, the color of white sand is relatively constant and very light.

Some sand on the reef flat is indistinguishable from mud as both are of terriginous origin. Field checking is the only way to discriminate these. Also the more distant from a source of run off, the more likely the sediment is dominated by sand.

Mud:

Mud is clearly chocolate brown and usually has a very smooth texture in the IKONOS imagery. Mud is associated with run off or dredging, which may be obvious in the image, or occurs in very protected areas such as Kaneohe Bay where its source is usually obscured by the dense foliage on shore. Only in extremely protected areas does mud extend more than 25 meters seaward of the shoreline.

Macroalgae

Macroalgae is the most common habitat on reef flat or back reef and is more likely to be dense closer to shore as long as unconsolidated sediment is absent. The color is darker than the surrounding sandy or uncolonized hard bottom areas. Areas where algae are the densest are usually darker than the less dense areas. Also, look for uniform dark areas to identify continuous algae.

Relief in these areas is typically low. In the center of the reef flat it is usually less than 1 meter. At the inshore area of the reef flat it is usually less than 0.5 meter. On the outer part of the reef flat it is usually 1 to 2 meters with the shallow areas often limited by tidal fluctuation. The majority of the reef flat is typically dominated by macroalgae.

10-<50% Cover:

This habitat can be identified as being typically darker than the surrounding sand. It is often olive green to tan.

50-<90% cover:

This habitat can be identified as being darker than 10-<50% cover.

90-100% Cover:

This habitat can be identified as being darker than 50-<90% cover and is often nearly black and displays little irregularity.

Coral Reef and Colonized Hardbottom

Aggregated Coral

This habitat occurs sporadically at the seaward edge of the reef flat. In this area relief is moderate and as live coral is not distinguishable in the imagery, this habitat has not been delineated unless field validation has been conducted.

Scattered Coral/Rock in Unconsolidated Sediment

This is a common habitat on the seaward edge of the reef flat and may be easily identified but equally as easily missed when interpreting IKONOS imagery. As the resolution of IKONOS imagery is 4 meters, debris and coral that meet the description of this habitat create a specked appearance in the imagery. This is only true if the debris and coral are of adequate size to generate sufficient differences in the spectral composition from pixel to pixel to be able to detect them visually. If the data support this visual distinction then the area will be classified correctly. If the coral and rock is to small to be detected visually, the area will be classified as sand and will contribute to error. This error is inherent to interpreting this type of imagery.

Look for a specked appearance on a sand background on the outer reef flat or back reef to identify this habitat in the imagery.

Colonized Pavement

Colonized pavement on the reef flat and back reef occurs only on the seaward side. As the seaward edge is approached, the probability of encountering live coral increases. As coral reef managers are interested in the presence of live coral, this characteristic takes priority over others such as macro or encrusting coralline algae. Therefore, look for this habitat on the seaward side of the reef flat. It is usually a reddish or gray color and is highly irregular from one pixel to the next. The irregularity in this area is due to the complexity of the relief causing shadows and highly illuminated areas close to one another. Furthermore, the upward growth of these features is limited by tidal fluctuations so the top of the platform may be desiccated periodically. The tops of platforms where desiccation occurs are devoid of coral and usually devoid of algae with the exception of encrusting coralline algae or turf species. All of this diversity leads to high visual complexity.

Look for a gray to reddish color with high variability from pixel to pixel on the seaward edge of the reef flat or back reef. It is important to note that this same appearance in this location can constitute uncolonized pavement as well. When delineating this habitat from Ikonos imagery, general field knowledge of the area is essential.

Colonized Pavement with Sand Channels

This habitat does occur on the reef flat but it is very uncommon. One example is at Kiholo Bay on the Island of Hawaii. When this habitat occurs on the reef flat it is a series of alternating carbonate fingers running perpendicular to land (in the direction of wave surge) and the fingers are separated by sand. A similar but distinctly different habitat occurs where the seaward edge of the reef flat is continuous carbonate (colonized or uncolonized by live coral) structural reef that ends in finger like extensions on the reef flat or back reef. These finger like extensions are almost never colonized with coral but are usually heavily populated with macroalgae.

Look for strips of carbonate substrate interspersed and completely isolated by strips of sand on the reef flat oriented perpendicular to shore. The sand and carbonate features are narrow, usually no more than 5 to 10 meters wide.

Uncolonized Hardbottom

Reef Rubble

This habitat occurs on the seaward side of the reef flat where coral debris that is dislodged during high surf episodes and cast over the reef crest is deposited in pockets where the water motion decreases as the wave energy is spent. The best way to identify this habitat is to look for channels in the reef crest with the axis of the color in the pixels radiating landward onto the reef flat. Another way to locate this habitat is to identify the depression directly landward of the reef crest where this debris accumulates. The depression is usually not more than 1 meter deeper than the reef crest or if there is no reef crest, 1 meter deeper than the shallowest part of the fore reef. In this last case, high-resolution bathymetry is extremely helpful.

As the reef crest is usually very shallow and is often exposed at low tide, look for an increase of up to 1 meter depth directly behind the reef crest or a channel where rubble would be funneled from the fore reef and reef crest onto the reef flat.

Uncolonized Pavement

Uncolonized pavement is one of the most common habitats on the reef flat. On the landward segment of the reef flat, remove the areas delineated as sand, macro algae or mud and the remainder is uncolonized pavement. This area may be very light colored but typically has more texture than sand. It may be dark colored due to terriginous deposits of sediment or a thin film of turf/microbiological growth such as diatom or bacterial films or filamentous algae. This habitat has more texture than sand but less texture than macroalgae.

On the seaward segment of the reef flat, field validation is needed to confirm that the pavement is not colonized (See discussion on colonized pavement above). The exception to this rule is where the reef flat is very shallow for large areas forming a flat platform the height of which is limited by tidal fluctuation. These areas have a uniform tan color and are located directly landward of the reef crest.

Encrusting/Coralline Algae

This habitat rarely occurs on the reef flat. It is most common on the reef crest. It is indistinguishable from uncolonized pavement and has not been delineated in this zone.

Other delineations

Emergent Vegetation

This habitat does not occur on the reef flat but isolated recruits of the aggressive red mangrove (an alien invasive species) are rapidly colonizing the reef flats throughout the State of Hawaii. These recruits trap and stabilize the sediment resulting in conversion of reef flat into shoreline intertidal so all mangrove area is, or soon will be, shoreline intertidal.

Fish Ponds

This is an archeological feature of ancient Hawaiian culture where fish were surrounded, captured and released into man made pens that were constructed of volcanic boulders. These pens were constructed on the reef flat adjacent to shore. Today they exist in various stages of repair. Some have been completely restored and can be seen as distinct semicircular walls with each end attached to shore. Look for a dark narrow semicircular feature surrounding an area that meets the description of reef flat mud. Where these features are intact, the entire pond, including the rock wall, is delineated. Where the pond is in disrepair, the volcanic rocks are strewn across the reef flat and the interior of the fish pond has reverted to unaltered reef flat typical of the near shore habitats that occur outside of fish pond. In this case, the boulders are covered with algae and are designated as such and the interior of the pond is designated as algae/sand/mud as described above. A fish pond in disrepair is not delineated as a fish pond.

Look for the dark semicircular band indicating a fish pond. If the band is intact, designate it as a fishpond. If it is not intact, delineate the area as the habitat on the reef flat described above using macroalgae (usually continuous) for the rock boulder areas and algae, mud or sand for the remainder.

Other Manmade Features

This habitat is used for any structures such as piers, wharfs, or jetties. These are often constructed from the reef shoreline and cross the entire reef flat ending in the lagoon. Look for features with uniform light color where sections are very linear and distinct angles occur between the sections.

3. Lagoon Zone

Water quality in lagoons is highly variable. The only true lagoon in the Main Eight Hawaiian Islands is in Kaneohe Bay where the bottom is completely obscured by turbidity. It is well known that the lagoon floor in Kaneohe Bay is composed of a combination of terriginous and carbonate mud. Therefore, the entire lagoon habitat is mapped as mud. The only exception is the large individual patch reefs that extend to the lagoon surface where their upward growth is limited by tidal fluctuation.

The lagoons of the atolls of the Northwestern Hawaiian Islands, where water quality is often very good still suffer from the same limitation of episodes of poor water quality. Thus, this report will address only those areas where water quality is commonly good enough to have a clear view of the lagoon floor. As these areas all occur in the Northwestern Hawaiian Islands and photointerpretation of benthic habitats of the Northwestern Hawaiian Islands has not been undertaken, this data should be viewed in this context.

Unconsolidated Sediment

The majority of the habitat in most lagoons is sand or mud.

Sand:

Sand appears bright white to light blue to darker blues depending on depth with shallower areas being lighter. From pixel to adjacent pixel, sand is frequently very uniform. There is little change in color or texture over areas where depth is consistent. Sand waves often cause rippled looking surfaces on the lagoon floor but these differences are easily identified. The color of white sand is relatively constant and very light.

Mud:

There is often a sharp transition from the shallow to a deep section of the lagoon. Turbidity often obscures the bottom of the deep area but the substrate in the deep area is usually composed of carbonate mud. Look for a uniform darker area where the lagoon floor is not visible.

Macroalgae

Most macro algae are fastened to hard substrate even though it may be as small as a chip of reef rubble. As a result, macroalgae is usually not present on lagoon sand unless it is a very protected area. Most lagoon algae are fastened to areas of reef rubble, pavement or relic patch reefs.

Look for areas distinctly darker than the surrounding sand. Dark areas that are surrounded by sand are usually relic patch reefs that are now devoid of live coral. These patch reefs can extend from1 meter above the lagoon floor to the lagoon surface.

Also look for large darker areas that have less than 1 meter of relief. These areas are often pavement colonized by algae. Also look for dark patches in very sheltered depressions. These are often thick mats of algae.

With the exception of the tops of patch reefs where the pavement is very light colored, all hard bottom areas in a lagoon that have not been designated as colonized by coral should be designated as colonized by algae. In general, the density of algae is based on the darkness of brown to olive green. The lighter areas are the less dense and the darker are denser.

10-<50% Cover:

Areas of light brown or olive green that have not been designated as colonized by coral and are distinctly not sand should be classified as 10-<50% algal cover.

50-<90% cover:

Areas of medium density brown or olive green that have not been designated as colonized by coral and are distinctly not sand should be classified as 50-<90% algal cover.

90-100% Cover:

Areas of dark brown or olive green to dark gray or black that have not been designated as colonized by coral and are distinctly not sand should be classified as 90-100% algal cover.

Coral Reef and Colonized Hardbottom

Individual Patch Reef

This habitat is common in lagoons of the Hawaiian Islands. When delineating patch reefs, look for two distinct types; those that have grown to the surface and are limited by tidal fluctuation and those that are submerged and upward growth is not limited by tidal fluctuation. Those in Kaneohe Bay lagoon and the reticulated reefs in Pearl and Hermes reef lagoon typify the first type. These reefs typically have significant cover of live coral around their edge extending to the lagoon floor on the windward side of the feature. The surface of the reef is usually ringed with algae mixed with live coral and the center of the reef is a veneer of sand over laid on pavement. The smaller reefs may lack the sand in the center. Look for distinct variation in the habitat types of the surface of these reefs. The center will be bright white with a tendency to blue if the center is deep. The edges will be brown where the algae is dominant and the rim will be dark and the slope is steep where the dense coral is growing.

Look for circular or elongated features with distinct contrast to the sand or mud around them and steep slope on the sides that are larger than the minimum mapping unit.

The second type is not limited by upward growth. These are frequently smaller and usually lack variation of habitat types. Look for a dark feature that is in contrast to the light sand or pavement around it and is larger than the minimum mapping unit. These features usually have a vertical relief of 1 meter or more. If it is determined that the feature is colonized with live coral, delineate it as a patch reef. If it is not colonized, delineate it as algae.

Aggregated Patch Reef

This habitat is reserved for areas where there are many small patch reefs that are to small to meet the minimum mapping unit. The same rules will apply to this feature as are applied to the individual patch reef only as each reef is too small to meet the minimum mapping unit, more than one will be delineated into a single polygon. Look for small dark areas that are in contrast to the sand or pavement around them and have been determined to be colonized by live coral. If they have not been determined to be colonized by live coral assign the habitat of algae.

Scattered Coral/Rock in Unconsolidated Sediment

This is a common habitat on the outer edge of the lagoon where large surf frequently surges over the reef crest and deposits coral and debris on the lagoon floor. These fragments often grow to form small coral colonies that, when large enough, are detectable in IKONOS imagery. The northern edge of the lagoon at Kure and Midway atolls are good examples of these but this habitat does not occur in the lagoon of Kaneohe Bay. It is easily identified but equally as easily missed when interpreting IKONOS imagery. Look for a specked appearance or streaked lines of strewn debris in the imagery. If the coral and rock is too small to be detected visually, the area will be classified as sand and will contribute to error. This error is inherent to interpreting this type of imagery.

Colonized Pavement

Colonized pavement in the lagoon is very rare. If this habitat occurs is will look like patch reef habitat but will lack the vertical relief. Use the rules for patch reef but reduce the vertical relief to less than one meter. If this habitat occurs in the lagoon it will be on the perimeter and may be included in the reef flat or back reef zone.

Uncolonized Hardbottom

Reef Rubble

This is a common habitat in lagoons. Look for light gray streaks that are in slight contrast to the surrounding sand and lack the speckled appearance of scattered coral and rock. These areas are often associated with and overlap with scattered coral and rock but are not colonized.

Uncolonized Pavement

This is a common habitat in lagoons. Look for light colored areas that are only slightly different than the surrounding sand. These areas are not oriented in any particular direction or have any particular shape. They can be very light and are frequently mis-attributed as sand. Pavement often has a distinct edge as it is usually slightly elevated off the lagoon floor and the edge causes a slightly darker appearance.

Encrusting/Coralline Algae

The most common place this habitat is found in the lagoon is on top of shallow patch reefs. This is often a thin rim on the windward side. Look for a thin line of very light color on the windward side of an emergent patch reef.

10-<50% Cover:

Density will be difficult to determine but generally the lighter the rim the more dense the encrusting algae. Look for a dim light rim to delineate 10-<50% cover.

50-<90% Cover:

Look for a medium light rim to delineate 50-<90% cover.

90-100% Cover:

Look for a very bright rim to delineate continuous encrusting coralline algae.

Other delineations

Other Manmade Features

This habitat is used for any structures such as piers, wharfs, or jetties. These often extend from the shoreline into the lagoon. Look for features with uniform light color where sections are very linear and distinct angles occur between the sections.

4. Reef Crest Zone

Macroalgae

Macro algae often occur on the reef crest. These areas look dark brown to tan in color. However the reef crest us usually covered by white water and the algae is not visible.

10-<50% Cover:

Look for light brown but not cream color.

50-<90% cover:

Look for darker brown about chocolate color

90-100% Cover:

Look for very dark brown to nearly black.

Coral Reef and Colonized Hardbottom

Linear Reef

This class can be a conglomeration of other habitats. Look for a linear feature that runs parallel to shore and a depth of less than 1 meter with a depth that is about 0.5 meter shallower than the reef flat. This feature is usually cream to reddish colored on the reef flat side (uncolonized pavement) and darker in the center (macro algae) and has a pink shade on the seaward side (Encrusting Coralline Algae). The entire reef crest can be a linear reef.

Uncolonized Hardbottom

Reef Rubble

Though reef rubble does occur in the cracks and deep depressions on the reef crest, an area large enough to meet the minimum mapping unit of 1 acre has not been encountered in the Main Eight Hawaiian Islands. It is not likely that a quarter of an acre minimum mapping unit of reef rubble on the reef crest would be met in either the Main Hawaiian Islands or the Northwestern Hawaiian Islands.

Uncolonized Pavement

This is one of the most common habitats on the reef crest. It is typically very light colored but not as bright as sand. It is also less uniform than sand and often has an abrupt edge particularly on the landward side of the reef crest.

Encrusting/Coralline Algae

This habitat is very common on the side of the reef crest exposed to high wave energy but is very difficult to see in the IKONOS imagery. The pink hue that is apparent in the field is rarely apparent in the imagery. Instead, it appears as a white to cream-colored strip that is often in the wash of white water. This is the highest energy regime in the reef system. It is usually only present on distinct reef crests or on the top of relic reef that may form a discontinuous reef crest. If a distinct reef crest or a distinct discontinuous reef crest is visible and the seas are very calm, look for a light cream-colored strip on the seaward side. Also look for mottled surface that may represent high relief where the shallow surfaces are encrusted with coralline algae.

10-<50% Cover:

Substrate that is encrusted by coralline algae is often heavily encrusted but is frequently limited to the shallow upward facing surfaces. Thus if encrusting coralline algae is visible, there will most likely be at least 50% cover.

50-<90% cover:

Look at the leading edge of the reef crest. This area is frequently covered at this density.

90-100% Cover:

Look at the top of the reef crest of an atoll where the surf washes over the reef. This area often has a continuous cover of encrusting coralline algae.

5. Fore Reef Zone

The fore reef is characterized by being a high-energy zone seaward of the reef crest and landward of the bank/shelf and typically has a steeper slope than the zones that are adjacent. This area is the part of the reef system that is actively growing seaward. Therefore it often supports robust coral growth.

Unconsolidated Sediment

Sand:

Sand on the fore reef is typically in reef holes, depressions and channels. However, the depth increases rapidly in the seaward direction so expect the bright white sand to be darker blue offshore.

Macroalgae

Macroalgae occurs on the fore reef and is usually sparse in the shallower high-energy areas. It dominates most substrate that is not colonized by live coral unless the area is completely uncolonized pavement. The shallowest parts of the fore reef are commonly nearly devoid of macro algae. These areas are colonized by varying density of filamentous turf and appear very light color. Thus, remove the areas that are sand, those colonized by coral and the area that appears very light and attribute the remainder as macro algae. The exception to this are the coral reef habitats that are obligate colonized in the classification scheme such as spur and groove and linear reef. These are assumed to be colonized by live coral so should not be included as options to be classified as macroalgae.

10-<50% Cover: After removal of sand, colonized and uncolonized hard bottom, classify the remainder as macroalgae. Macroalgae on the fore reef is rarely denser than 10-<50% cover and looks brown to olive green.

Coral Reef and Colonized Hardbottom

Linear Reef

This habitat can be a conglomerate of several habitats but must be a feature that is linear and runs perpendicular to shore. If the feature is composed of many habitats such as spur and groove or uncolonized pavement, significant habitat information is lost if this option is exercised. If the habitat diversity on the linear reef is low, this option is favored. Thus, in the mapping that has been conducted for the Main Eight Hawaiian Islands, this habitat has been used only rarely. In the imagery, look for uniform areas that lack spur and groove or channel features and appear to lack high relief. If this feature is parallel to shore, such as along a fringing reef, delineate it as linear reef.

Aggregated Coral

Aggregated coral is common on the deeper areas of the fore reef along coastline where coral is prominent. It is usually dark color and can approach black. It is very uniform from pixel to pixel. Look for the uniformity on the deeper part of the fore reef as the habitat is defined as solid coral.

Spur and Groove and Colonized Pavement with Sand Channels

The alternating deep channels and shallow spurs that are oriented perpendicular to the prevailing wave direction distinguish this habitat. Spurs can be a few meters apart in the shallow area of the fore reef to 10s of meters apart in the deeper part of the fore reef. The grooves can be very narrow (1 meter) on the upper fore reef to very wide (10s of meters) on the deeper fore reef or shelf. The narrow grooves in the shallow areas often cause a shadow in the groove that makes it appear dark. In this case, this habitat looks like alternating narrow dark lines. In deeper areas where the spur is wider, the groove may look white due to sand in the bottom of the groove so the image looks like alternating white and dark lines. The feature that distinguishes this habitat from colonized pavement with sand channels is the steepness of the sides of the groove. Colonized pavement with sand channels is a rolling or shallow channel typically less than a meter in depth. Spur and groove has a steep channel wall that is nearly vertical and is usually more than a meter in depth. Look for these alternating light and dark features. Spur and groove on the shallow fore reef often becomes pavement with sand channels on the deep fore reef and shelf thus there is not always a clear line between them.

Colonized Pavement

This habitat usually occurs on the shallow part of the fore reef where it is common. Look for the absence of sand or spur and groove and if the area is tan to dark color and it is known that the area is predominately colonized by live coral, designate this area as colonized pavement. Recognize that this classification scheme does not accommodate relief other than in spur and groove and sand channels. Thus pavement can have significant relief and the color can be very dark brown and have very irregular density from pixel to pixel.

Uncolonized Hardbottom

Uncolonized Pavement

This is one of the common habitats on the upper fore reef. Uncolonized pavement is most easily identified as being very light color often having a tan, cream or reddish tinge. It is recognized however that areas of high relief can result in uncolonized pavement being very dark color and may be indistinguishable from macro algal covered substrate or substrate where the relief is high and supports sufficient live coral to be classified as colonized. First look for the pale colored areas then look for dark colored areas where color is irregular from pixel to pixel. Highly variable areas on the upper fore reef usually indicate high relief. Then use field knowledge to decide if the area is colonized or not colonized with live coral.

Encrusting/Coralline Algae

On the landward edge of the upper part of the fore reef, directly adjacent to the reef crest, encrusting coralline algae often occurs on the top of relic coral heads that are surrounded by deep channels. This habitat can rarely be seen in IKONOS imagery and has been typically included with the reef crest polygons.

6. Bank/Shelf Zone

In the deeper water of the bank/shelf zone, the spectral composition of the imagery is somewhat compromised. Nearly all habitats look very similar in color and are, at best, a gradient of grays with the consistent transparent blue from the water column prior to compensation for the water column. This complication has been minimized by removal of spectral interference of the water column but interpretation of deep-water features is, never the less, more challenging. With the exception of sand, most delineation of habitats is based on light vs. dark features, gross reef morphology and familiarity with the area that is being mapped. Therefore, all habitat delineation, with the exception of sand, is based on the initial dichotomous decision of whether coral is present at sufficient levels to conclude that the area is colonized.

If it is determined that the area is not colonized with coral, enter the classification scheme at “Macroalgae” or “Uncolonized Hardbottom”. If it is determined that the area is colonized by sufficient live coral to qualify as “Coral Reef and Colonized Hardbottom”, then enter the classification scheme at this level.

It is also important to recognize that the Bank/Shelf can start at the seaward side of the intertidal if a fringing reef is not present. The rules for determining the habitats on the Bank/Shelf in shallow water in the absence of a fringing reef should be observed the same as the deeper areas of the Bank/Shelf zone.

It should also be recognized that the Bank/Shelf zone often extends inshore to the shoreline intertidal zone. This is the case where no structural reef is present. The majority of the coastlines of the younger islands have this zonation.

Unconsolidated Sediment

Sand:

Sand appears bright white to light blue to darker blues depending on depth with shallower areas being lighter. As the water on the shelf can range from the low tide line to as deep as the imagery can be interpreted, expect the sand to be white to medium blue to dark purple. In the deepest water, sand is most easily identified when it is adjacent to a hard bottom feature. Use the contrast between the white sand and the dark character of deep-water hard bottom features to easily select sand on the shelf.

Macroalgae

The area is not white like sand but is not light colored like uncolonized pavement. The area has a range of darkness that ranges from light blue-gray to black.

10-<50% Cover:

This area has sporadic dark patches that are frequently not attached to one another or are very sparsely distributed with white substrate between.

50-<90% Cover:

This class has consistent dark areas with light patches sporadically distributed though it.

90-100% Cover:

This area is continuous dark with little in the way of light patches and is usually nearly black.

Coral Reef and Colonized Hardbottom

Linear Reef

This class occurs on the shelf as dark streaks that run parallel to shore. Relief is low and the feature is often colonized by aggregated coral or colonized pavement. They are usually on a sand background.

Aggregated Coral

These features dominate the deeper areas where coral is abundant on the fore reef or inshore areas of the shelf. The color in the imagery is nearly black and the inshore area usually forms a mosaic of fingers and patches through a background composed of white sand. The outer edge is often continuous and ends at a clear transition to sand. The sand areas between the fingers are large (Usually over 10 meters but up to 100 meters) and meander through the coral. At the inshore side of this feature, the fingers often breakup into large patches of aggregated coral that can be classified as patch reefs. These all form bright contrast with the surrounding sand. These features usually rise less than 2 meters from the surrounding sand and are composed of nearly 100% coral cover.

Spur and Groove

On the shelf, the spurs are typically separated by grooves that are at least 10 meters wide and are composed of white sand. The spurs are usually heavily colonized with live coral causing them to appear very dark in color. This feature appears as alternate light and dark bands running in the direction of the prevailing swell, which is approximately perpendicular to shore. This feature is an extension of the spur and groove system on the fore reef and usually does not extend beyond 15 meters depth.

Individual Patch Reef

Individual patch reefs occur on the shelf as dark areas usually surrounded by sand. The transition between the sand and the patch reef is sharp. These reefs can be, and often are, very similar to the aggregated coral class described above in this shelf zone with the exception that they are isolated islands of coral surrounded by sand.

Scattered Coral/Rock in Unconsolidated Sediment

In shelf areas where no reef flat is inshore, volcanic rock can be strewn by wave action and some coral colonization can occur. Look for very mottled or speckled areas along coastlines where coral colonization is probable.

Colonized Pavement

Colonized pavement is very common in areas where coral colonization is probable and extensive areas of the seafloor are very flat at depths greater than 10 meters. The windward sides of the older islands are the most likely to support this habitat. Look for uniform medium to light gray with little variation in color or texture and depth.

C*olonized Volcanic Rock/Boulder*

This habitat is most common on the younger un-weathered islands or on coastlines that are exposed to trade or strong weather. Areas less than 10 meters deep are not usually colonized with coral unless located on a protected coastline. The more exposed the shoreline, the deeper the transition from uncolonized to colonized habitat. In general, very exposed areas will be uncolonized above 20 meters. Areas of moderate exposure will be colonized below 5 to 10 meters and protected areas are usually colonized up to 1 to 2 meters. This habitat is commonly found as foreheads of rock that fan out from the shoreline or as the deeper areas offshore of coastlines where rock cliffs drop steeply to the sea. Most of these areas are colonized at some depth.

Colonized Pavement with Sand Channels

Use the description of Colonized Pavement and include the possibility of sand channels being visible. The sand channels can be narrow. These are often 1 meter wide or less and may not be visible in IKONOS imagery. If they are visible, they will appear as light colored lines that are usually 5 to 20 meters apart and run in the direction of the prevailing surf which is usually approximately perpendicular to shore.

Uncolonized Hardbottom

Uncolonized Pavement

Use the same rules as those for Colonized Pavement only apply to areas where coral colonization is not probable. These may include the lee or north facing coastlines of the islands.

Uncolonized Volcanic Rock/Boulder

Use the rules of Colonized Volcanic Rock/Boulder and select the area above the transition for colonized to uncolonized habitats.

Uncolonized Pavement with Sand Channels

Use the rules for Colonized Pavement with Sand Channels only apply this to areas where the probability of colonization of live coral is low.

7. Channel Zone

The habitats in a channel will look the same as the zone through which the channel is passing. As a channel can pass through several zones, use the rules for the zone adjacent to the portion of the channel that is being delineated.

8. Dredged Zone

This zone should be masked and manually delineated. The habitats in a dredged area are rarely visible as these areas are almost always turbid and rarely support habitat types other than sand, mud, reef rubble or algae. Further more, the area where dredging stopped is almost never detectable in the imagery.

V. Summary of Rules

1. Shoreline Intertidal Zone

Unconsolidated Sediment

Sand:

- Smooth texture (little variation from pixel to pixel)
- Bright white or
- Black or gray if adjacent to young lava flows

Mud:

- Chocolate brown
- Smooth texture
- Look for indications that there is terriginous runoff or dredging has occurred
- Mud areas are very sheltered such as areas adjacent to mangroves

Macroalgae

- Dark green to dark brown
- Strip in the surf zone (Often partially obscured by white water)
- Usually does not extend into more than 2 meters of water depth
- Frequently adjacent to a sandy beach
- Density is usually between 50-<90% cover
- Lighter colored areas can be assigned 10-<50% cover

If the near shore area that is off shore of the intertidal is very dark brown (Most likely continuous algae) and the beach rock is very dark brown, then attribute this area with "Continuous Macroalgae".

Uncolonized Hard Bottom

Uncolonized Volcanic Rock/Boulder:

- Not emergent vegetation, sand, mud, uncolonized pavement or algae
- High contrast between pixels across very short distances
- Area that is wet during the image acquisition is usually very dark and almost black

Other Delineations

Emergent Vegetation

- Continuous forest green
- Sharp contrast with the muddy environment offshore
- Landward edge of this habitat is nearly impossible to delineate as these trees merge with other green forest vegetation

Hardened Substrate

- Rarely identifiable in IKONOS imagery
- A long uniform narrow feature in the shoreline intertidal typically
- Often sand on the seaward side
- The feature itself may or may not be visible as in the imagery but a very straight line running along the shore is usually a retaining or erosion control devise

Other Manmade Features

Uniform light color

Sections are very linear

Distinct angles occur

2. Reef Flat and Back Reef Zones

Unconsolidated Sediment

Sand:

- Bright white to light blue depending on depth with shallower areas being lighter
- May be brown if terriginous input exists near by (very difficult to distinguish from mud
- Smooth texture (little variation from pixel to pixel)

Mud:

- Chocolate brown
- Smooth texture (little variation from pixel to pixel)
- Rarely extends more than 25 meters seaward of the shoreline

Macroalgae

- Darker than the surrounding sand
- Darker than the uncolonized hard bottom areas
- Darkest areas are denser than less dark areas
- Uniform dark areas to identify continuous algae
- The majority of the reef flat is typically dominated by macroalgae.

10-<50% Cover:

- Darker than the surrounding sand
- It is often olive green to tan

50-<90% cover:

- Darker than 10-<50% cover.

90-100% Cover:

- Darker than 50-<90% cover and is often nearly black
- Displays little irregularity – color is uniform

Coral Reef and Colonized Hardbottom

Aggregated Coral

- Not delineated unless field validation has been conducted

Scattered Coral/Rock in Unconsolidated Sediment

- Located on outer reef flat
- Specked appearance on a sand background
- Easily missed as debris may be too small to create an adequate contrast from pixel to pixel in IKONOS imagery

Colonized Pavement

- Seaward side of the reef flat
- Reddish or gray color
- Highly irregular from one pixel to the next
- Field knowledge is needed to distinguish this from uncolonized pavement

Colonized Pavement with Sand Channels

- Series of alternating carbonate fingers running perpendicular to land (in the direction of wave surge)
- Fingers are completely separated by sand
- Oriented approximately perpendicular to shore
- Sand and carbonate features are narrow, usually no more than 5 to 10 meters wide

Uncolonized Hardbottom

Reef Rubble

- Depression on the seaward side of the reef flat
- Usually no more than 1 meter deeper than the reef crest
- Not sand
- Axis density gradients usually radiating landward onto the reef flat
- Also look for a channel where rubble would be funneled through from the fore reef and reef crest onto the free flat.

Uncolonized Pavement

- On the landward half of the reef flat, remove the areas delineated as sand, macro algae or mud and the remainder is uncolonized pavement
- Very light colored but typically has more texture than sand
- May be dark colored due to terriginous deposits of sediment
- Very shallow for large areas forming a flat platform the height of which is limited by tidal fluctuation. These areas have a uniform tan color and are located directly landward of the reef crest

Other Delineations

Fish Ponds

- Semicircular long narrow feature (less than 10 meters wide) with each end attached to shore
- Dark color
- Internal area meets the description of reef flat mud

Other Manmade Features

- Uniform light color
- Sections are very linear
- Distinct angles occur between the sections

3. Lagoon Zone

Unconsolidated Sediment

Sand:

- Bright white to light blue depending on depth with shallower areas being lighter
- May be brown if terriginous input exists near by (very difficult to distinguish from mud
- Smooth texture (little variation from pixel to pixel)

Mud:

- Uniform darker area
- Lagoon floor is not visible
- Assume mud

Macroalgae

- Darker than the surrounding sand
- Less than 1 meter of vertical relief
- Dark patches in very sheltered depressions
- Not coral or sand

10-<50% Cover:

- Light brown or olive green

50-<90% cover:

- Medium density brown or olive green

90-100% Cover:

- Dark brown or olive green to dark gray or black

Coral Reef and Colonized Hardbottom

Individual Patch Reef

Type 1:

- Center will be bright white with a tendency to blue if the center is deep (Some lack this feature)
- The edges will be brown where the algae is dominant
- The rim will be dark and the slope is steep where the dense coral is growing
- Roughly circular or elongated features

Type 2:

- Dark feature that is in contrast to the light sand or pavement around it
- Vertical relief greater than one meter
- Larger than the minimum mapping unit
- If it is determined that the feature is colonized with live coral delineate it as a patch reef, if it is not colonized delineate it as algae

Aggregated Patch Reef

- Dark feature that is in contrast to the light sand or pavement around it
- Vertical relief greater than 1 meter
- Smaller than the minimum mapping unit
- More than one feature in the area of a
- If it is determined that the feature is colonized with live coral delineate them in a single polygon attributed as aggregated patch reef, if it is not colonized, delineate it as algae

Scattered Coral/Rock in Unconsolidated Sediment

- Mostly sand
- Specked appearance or streaked lines of strewn debris

Colonized Pavement

- Not light colored
- Use the rules for type 2 patch reef but reduce the vertical relief to less than 1 meter
- If it is determined that it is not colonized with live coral, attribute as algae

Uncolonized Hardbottom

Reef Rubble

- Light gray streaks that are in slight contrast to the surrounding sand
- Oriented in the direction of wave surge

Uncolonized Pavement

- Look for light colored areas that are only slightly darker than the surrounding sand
- Not oriented in any particular direction or have any particular shape
- Often has a distinct edge as it is usually slightly elevated off the lagoon floor and the edge causes a slightly darker appearance

Encrusting/Coralline Algae

- Thin light colored rim usually less that 10 meters wide on the windward side of Type 1 patch reefs

10-<50% Cover:

- Dim light gray to white rim

50-<90% Cover:

- Medium light gray to white rim

90-100% Cover:

- Bright light gray to white rim

Other Delineations

Other Manmade Features

- Uniform light color
- Sections are very linear
- Distinct angles occur between the sections.

4. Reef Crest Zone

Macroalgae

- Dark brown to tan in color

10-<50% Cover:

- Light brown but not cream color

50-<90% cover:

- Darker brown about chocolate color

90-100% Cover:

- Very dark brown to nearly black

Coral Reef and Colonized Hardbottom

Linear Reef

- Linear feature that runs parallel to shore
- Depth of up to 1 meter
- Half meter shallower than the reef flat
- Cream to reddish colored on the reef flat side
- Darker in the center
- Pink or light colored on the seaward side

Uncolonized Hardbottom

Uncolonized Pavement

- Very light colored
- Not as bright as sand
- Less uniform from pixel to pixel than sand
- Often has an abrupt edge on the landward side of the reef crest

Encrusting/Coralline Algae

- Found in high water motion regime on the seaward side of the reef crest
- White to cream-colored in contrast to brown of algae
- May have mottled appearance on the seaward side where relief is high

10-<50% Cover:

- Rare

50-<90% Cover:

- Light colored

90-100% Cover:

- Pinkish hue

5. Fore Reef Zone

Unconsolidated Sediment

Sand:

- Bright white sand grading to darker blue in deeper water
- Holes and channels where depth increases by over 1 meter

Macroalgae

- Remove the areas that are sand
- Remove the areas that are colonized by coral
- Remove the areas that are very light
- Remove spur and groove and linear reef
- Attribute the remainder as macroalgae

10-<50% Cover:

- Medium brown

50-<90% Cover:

- Dark Brown

Coral Reef and Colonized Hardbottom

Linear Reef

- Uniform areas that lack spur and groove or channel features
- Lack high relief
- Parallel to shore

Aggregated Coral

- Dark color and can approach black
- Uniform from pixel to pixel

Spur and Groove and Colonized Pavement with Sand Channels

- Alternating deep channels and shallow spurs
- Oriented perpendicular to the prevailing wave direction
- To a depth of about 5 meters grooves are narrow (1 to 2 meters)
- Over 5 meters depth grooves are wider (over 2 meters)
- Over 5 meters depth, grooves are shallower
- Grooves under 5 meters depth are dark color
- Grooves over 5 meters depth are light color
- Sides of grove nearly vertical

Colonized Pavement

- Known that area is colonized by live coral
- No sand
- No spur and groove
- High or low relief
- Tan to dark color

Uncolonized Hardbottom

Uncolonized Pavement

- Known that area is not colonized by live coral
- No sand
- No spur and groove
- Pale color in shallow water (less than 3 meters deep) often light tan, cream or having a reddish tinge
- Dark color with high small scale relief

6. Bank/Shelf Zone

Unconsolidated Sediment

Sand:

- Bright white to dark blue depending on depth with shallower areas being lighter
- Smooth texture (little variation from pixel to pixel)

Macroalgae

- Not colonized
- Not sand
- Brown to blue-gray to black color

10-<50% Cover:

- Dark patches separated by sand or uncolonized pavement
- Dark areas not very dense - light brown (shallow) to blue-gray (deep)

50-<90% Cover:

- Consistent dark areas with light patches sporadically distributed though it
- Dark areas with moderate density

90-100% Cover:

- Very close to continuous dark areas
- Color is dark brown in shallow water to dark blue-gray to black in deep water

Coral Reef and Colonized Hardbottom

Linear Reef

- Dark streaks that run parallel to shore
- Usually surrounded by sand
- Relief is low (usually 2 meters or less)

Aggregated Coral

- Usually over 10 meters deep
- Coral is abundant on the fore reef or inshore areas of the shelf
- Nearly black
- Usually ends at a clear transition to sand
- Inshore area usually forms a mosaic of meandering fingers and patches through a background composed of white sand
- Fingers often break up into patch reefs (Type 2)
- The outer edge is often continuous
- Sand areas between fingers are large (Usually 10 to 100 meters across)
- Relief is usually less than 2 meters from the surrounding sand

Spur and Groove

- Spurs are typically separated by grooves that are at lest 10 meters wide
- Grooves are composed of white sand
- Spurs are very dark in color, often black
- Appears as alternate light and dark bands running in the direction of the prevailing swell which us approximately perpendicular to shore
- Extension of the spur and groove system on the fore reef and usually does not extend beyond 15 meters depth

Individual Patch Reef

- Known to be colonized or offshore of structural reef areas that are colonized by live coral
- Dark areas usually surrounded by sand
- The transition between the sand and the patch reef is sharp
- Vertical relief greater than 1 meter
- Larger than the minimum mapping unit

Aggregated Patch Reef

- Known to be colonized or offshore of structural reef areas that are colonized by live coral
- Dark feature that is in contrast to the light sand or pavement around it
- Vertical relief greater than 1 meter
- Smaller than the minimum mapping unit
- More than one feature in the area of a minimum mapping unit

Scattered Coral/Rock in Unconsolidated Sediment

- Mottled or speckled areas along coastlines where coral colonization is probable

Colonized Pavement

- Known to be colonized
- Uniform color pixel to pixel
- Tan in shallow water
- Dark tan in deep water
- Area flat

C*olonized Volcanic Rock/Boulder*

- Typical of younger un-weathered islands or on coastlines that are exposed to trade or strong weather
- Very exposed areas are uncolonized above 20 meters
- Moderately exposed areas are uncolonized above 5 to 10 meters
- Protected areas are usually colonized up to 1 to 2 meters
- This habitat is commonly found as foreheads of rock that fan out from the shoreline
- Deeper areas offshore of coastlines where rock cliffs drop steeply to the sea

Colonized Pavement with Sand Channels

- Use the description of Colonized Pavement and include the possibility of sand channels being visible
- Sand channels appear as light colored lines
- Five to 20 meters apart
- Run in the direction of the prevailing surf which is usually perpendicular to shore
- Slope is not steep in sides of channel

Uncolonized Hardbottom

Uncolonized Pavement

- Use the same rules as Colonized Pavement only apply to areas where coral colonization is not probable

Uncolonized Volcanic Rock/Boulder

- Use the rules of Colonized Volcanic Rock/Boulder only select the area above the transition for colonized to uncolonized habitats.

Uncolonized Pavement with Sand Channels

- Use the rules for Colonized Pavement with Sand Channels only apply this to areas where the probability of colonization of live coral is low.